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Alexander Nosich
Institute of Radio-Physics and Electronics of the National Academy of Sciences of Ukraine

RADAR PREHISTORY, SOVIET SIDE: THREE-COORDINATE *L*-BAND PULSE RADAR DEVELOPED IN UKRAINE IN THE LATE 30'S

Alexei A. Kostenko, Alexander I. Nosich and Irina A. Tishchenko

The A. Usikov Institute of Radio-Physics and Electronics
of the National Academy of Sciences, ul. Proskury 12, Kharkov 61085, Ukraine
fax: +380-572-441105, email: <alex@emt.kharkov.ua>

Introduction. Prehistory of radar in the UK and USA is well documented [1-3], and even less known radar developments in Japan and New Zealand are known [4,5]. However, early radar works in the USSR have been published scarcely, and only in Russian [6-8]. Now, more than 60 years after, they can be considered as pioneering in certain aspects. Here we review the history of designing a pulse radar of the *L* band in the Ukrainian Institute of Physics and Technology (UIPT) in Kharkov. This work was unique one in terms of ideas, scope, complexity of tasks, and time of completion. The basic concepts of radar design and many technical innovations were well ahead of the general trends in microwave engineering. However, at first because of political purges that smashed UIPT in the late 30's, and then of the loss of Kharkov in the fourth month of the war, this radar had never resulted in serial production. All the official archives on this radar were lost in the war. For this reason, our study used mainly private archives of the former staff, especially of the late Alexander Usikov (1904-1995) [9,10], and interview of Semion Braude (born 1911) [11], who is the only living member of radar team.

Magnetron development. By the beginning of the XX century, the city of Kharkov had turned into a large industrial, cultural and scientific center. Kharkov State University (KSU), the third oldest in Russia, was opened by imperial decree in 1805. One of its four initial departments was that of physics and mathematics, whose graduates like A. Lyapunov and V. Steklov gained it a high reputation. After the Communist revolution and bloody civil war, it was Kharkov that was chosen capital city of Soviet Ukraine, from 1919 to 1934. In 1921 a research department of physics was established in KSU headed by Prof. Dmitry Rozhansky. The interests of this remarkable scientist and educator were entirely in electricity and magnetism including high-frequency electromagnetic waves. However, it will be no mistake to say that his main discovery done in Kharkov was Abram Slutskin (1881-1950), lifetime researcher of magnetrons and pulse radar, and definitely one of those who had shaped modern radio science. He entered KSU in 1910, just before the arrival of Rozhansky, and soon became an active member of the latter's physical seminar. On graduation, he worked as assistant (1916-1928), and then as professor in the physics department. Slutskin had managed to foresee, at the early stage, many major trends in microwave electronics. The 20's were the years of active research on magnetron in many countries. Slutskin and his assistant D. Shteinberg were among the pioneers of this method. In 1924, they succeeded in generating oscillations with from 40 to 300 cm [12], and next year they reached =7.3 cm.

In 1928, a brand-new R&D center was founded in Kharkov – the UIPT. It had strongly influenced the progress in science in the USSR, especially solid-state, low-temperature, and nuclear physics [13]. UIPT director I. Obreimov and the bulk of the staff came from Leningrad (St. Petersburg) attracted by the promising research and career opportunities. They managed to establish active contacts with the West-European scientific community. The journal of UIPT was even published in German to facilitate international recognition. Due to this openness, science celebrities like N. Bohr, P. Dirac, etc. were frequent visitors. This added to the scientific potential of the institute. In 1932, the lithium nucleus was split in UIPT

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and later liquid hydrogen and helium were obtained thus proving that Kharkov had turned into one of the leading centers of physical science. In 1932 Obreimov offered Lev Landau, later a Nobel Prize winner, employment in UIPT. Landau was only 24, but already a world celebrity in theoretical physics. From 1932 till 1937, he headed the theoretical department of UIPT and also lectured in KSU.

The Laboratory of Electromagnetic Oscillations (LEMO) was established as a department of UIPT in 1930 and headed by Slutskin. Of eight departments, this was the only one headed by a Kharkov scientist. Slutskin investigated the mechanisms and conditions of excitation of split magnetrons, and developed a theory of the dynatron mode operation. By 1933, a group headed by Usikov had designed multi-segment-anode magnetrons for λ from 20 to 80 cm with the CW output power of 30 to 100 W [14]. These were the champion parameters at that time. P. Lelyakov invented a very successful magnetron with a hollow anode water-cooled from inside. CW power level up to 17 kW with 55% efficiency and λ=80 cm was achieved by Braude with an all-metal «barrel-type» oscillator. Sample tunable CW magnetron was designed, in which the frequency was tuned in the 30% band. At the same time, an extensive investigation of a pulse-mode device was carried out. This work was led by Usikov who discovered, in 1933, the effect of discontinuous modulation. A packaged uncooled magnetron with a linear cathode inserted in a glass case was developed. It provided the pulse power of up to 60 kW at λ from 60 to 65 cm. The progress in generating high-power oscillations drew attention of the military from the Technical Department of Red Army. One can judge the scale of pre-war research carried out in LEMO-UIPT by impressive number of published papers and dissertations. Thus, by the end of 1936, it had carried out a fundamental research program and had a complete set of the *L*-band magnetrons both for CW and pulse operation. This was a solid background for launching a complex work on developing pulse radar.

Pulse radars "Zenit" and "Rubin". Soviet radar studies started in 1933, led by two military establishments: Principal Department of Artillery (PDA), for gun aiming; and Department of Air Defense (DAD), for air surveillance. Despite USSR planned economy, to design advanced weapons in the shortest time, R&D efforts were often doubled and tripled by different teams and labs. PDA selected as more promising a Doppler radar in CW mode. Several teams in different laboratories tried to develop reliable and efficient device, some of them using Slutskin's magnetrons. They succeeded in detecting the targets, however these devices located only the distance and azimuth. DAD soon decided to support the pulse method studies as well. A Leningrad laboratory headed first by Rozhansky and then by Y. Kobzarev worked with the tubes of 40-50 kW, 10-μs pulses, and λ from 3.2 to 4.7 m. A test of radar demonstrated reliable detection of an aircraft at the distances of up to 55 km and the height of 1500 m [7,8].

In March 1937, in line with R&D project from the Red Army, Slutskin started designing a pulse gun-aiming radar of the *L* band, named "Zenit" [9,10]. Its transmitter used a magnetron with pulse power of 11 kW, wavelength 64 cm, pulse duration 10 μs. Two antennas were identical all-metal parabolic reflectors of 3-m diameter fed by in-focus half-wave dipoles. They were distanced about 50 m from each other, in order to reduce the jamming of sensitive receiver by the powerful pulses of transmitter. Both reflectors rotated synchronously in two planes. Usikov recalled that for making the first reflectors they used galvanized iron of the rainwater pipes of the UIPT building [10]. The beam-width of the amplitude radiation pattern was about 16° in the "equatorial plane". As mentioned, there is no available technical documentation about «Zenit» and its antennas. Therefore, this data, together with terminology, is based on the memories of those who heard it from the designers. Note that reflector antenna theory did not exist in the 30's, as well as horn feeds. Therefore, the «Zenit» antenna performance was far from

optimal in terms of edge illumination, gain, and sidelobe level. According to today's estimations done by the method of [15], a 5-λ dish fed by a dipole provides a 18/24° main beam with –7/10 dB sidelobe level, by amplitude, in the E/H-plane.

The beginning of radar work coincided with dramatic events in USSR and UIPT. 1937 was the ill-famous year of Stalin's terror going berserk. UIPT was literally paralyzed by a series of political purges, with Landau being the main target [13,16]. By 1937 this elite research center was in trouble: military projects had preference and were better paid that resulted in splitting the institute into two warring fractions with their sympathizers beyond the institute. A part of staff including Landau proposed to separate "non-physicists" of LEMO from the institute [16]. In the Orwellian atmosphere of the 30's, this internal conflict was actively exploited by the secret political police. Landau was pointed to as a leader of the "trotskist-sabotage group" and accused of "trying to spoil defense works in UIPT". He escaped to Moscow, to work with Petr Kapitsa, but was arrested in 1938 and spent one year in jail. Fortunately for LEMO, the work on the radar project played the role of protective shield. Besides, united by the team spirit, Slutskin's people kept perfectly friendly inside relations [11]. The first simple tests on detection of a flying target were carried out on October 14, 1938. Then, in 1939-1940 the situation inside UIPT became somewhat healthier, and LEMO worked intensively on the modified radar. In September 1940, it was presented to the joint commission of the Army and Navy experts. They concluded that radar was able to locate three coordinates (distance, azimuth and elevation) of single and group targets at the distance of 50 km, the heights up to 5000 m, within the time of 40 sec. As admitted by the chief military supervisor, gen. M. Lobanov, this was significant advantage over the meter-band radar [8]. Commission also noted some drawbacks, the most serious of which were two-antenna design, presence of dead zone and lack of continuous tracking necessary for the gunfire control. Funny enough, narrow beam-width was identified as additional demerit of "Zenit".

The plans for 1941 foresaw development of improved single-reflector radar. However, the war burning out Europe now turned East. As known, in 1941 the situation on the Soviet-German front developed dramatically. On August 23, 1941 at a meeting in the army headquarters Hitler rejected proposal to capture Moscow by all means and ordered to attack East Ukraine from the north. According to one of interpretations, his words were, «Kharkov is more important for me than Moscow». As known, this led to annihilation of the strongest Soviet divisions between Kiev and Kharkov, but gave the USSR the time needed to bring fresh forces from Siberia and defend Moscow. For our story, it is important that Kharkov was lost on October 24, 1941. However, as early as July, it was decided to evacuate UIPT to Central Asia. At that time, radar team was near Moscow, testing "Zenit" in battlefield conditions. Conclusion was that serious improvements were still necessary for reliable gun aiming, although air surveillance was successful. Therefore the LEMO team was sent to Bukhara, 3500 km from Kharkov, to work on the improved radar "Rubin".

This work took the whole 1942. The pulse power of transmitter was increased to 15 kW. Receiver was essentially a wide-band super-heterodyne with a double frequency conversion and had a high-frequency block (an *L*-band amplifier, the first mixer and the first heterodyne) and an intermediate-frequency amplifier. I. Truten had succeeded in solving the hard problem of protecting the receiver from high-power source pulses by using a gas discharger. It blocked the input of the receiver circuit when a pulse arrived. The «Rubin» antenna was designed as a 3-m grid parabolic dish with transmitter and receiver dipoles located in the focus. The dish was deployable and consisted of 6 segments made as a 20-mm cell, 2-mm diameter wire mesh [9]. The width of the main beam, by the half-level of amplitude, was 16/24°. A magnetron source with a stabilizing resonant circuit and receiver circuit were encased in hermetic case on the back of reflector. Rotation in

the vertical (0-90°) and horizontal (0-400°) planes was controlled remotely. The whole «Rubin» equipment was placed on two cars.

In 1943 «Rubin» was transported to Moscow and in 1944 to the Red Navy polar base Murmansk. Usikov's archive [9] contains a summary of two-month tests of radar performed there in the 5-km wide Vayenga Fiord. Aircraft detection was reliable within 40 km distance. Low-altitude targets, 30 to 50 m over the sea, were detectable. Mean errors were as follows: 120 m or less in distance, 0.8° or less in azimuth and elevation, the time of measuring any coordinate, by the null-reading technique, was 7 sec or less. Besides, «Rubin» enabled one to detect ships of all types: cruisers, freighters, on-surface submarines, speed motor-boats and wooden boats, with the same accuracy. Usikov had been always proud of this achievement and claimed that his team obtained the best results in radar in the USSR for that time. Till the end of the war, «Rubin» was used in the polar sector for surveillance.

Afterword. Decision to terminate the work on «Rubin» was influenced by the ambitions of the central defense laboratories and conservative thinking of the military. UK-designed meter-band gun-aiming radar GL-MkII was secretly re-engineered and put into serial production in 1942, under the name SON-2a. This was done at the time when the small team of LEMO was still struggling to develop «Rubin» in very difficult working conditions of Central Asia. Hence, it was no surprise that «Rubin» lost the competition. SON-2a was produced in the total quantity of 124 units during WW II. In addition, from 1943 long-range meter-band radar equipment was delivered from UK, USA and Canada via the *Lend-Lease* program. During the final stage of war, the Red Army used mainly these systems. It must be admitted, however, that on the Soviet-German front the radar was never a major factor, compared to its role in the Battle of Britain.

References

1. R.B. Colton, Radar in the U.S. Army, *Proc. IRE*, no 1, 1945.

2. W.C. Tinus, W.H.C. Higgins, Early fire-control radar for naval vessels, *The Bell System Tech. J.*, vol. 25, no 1, pp. 1-48, 1946.

3. D.G. Funk, *Radar Engineering*, NY: McGraw-Hill, 1947.

4. G. Sato, A secret story about the Yagi antenna, *IEEE Antennas Propagat. Magazine*, vol. 33, no 3, pp. 7-18, 1991.

5. R.S. Unwin, The development of radar in New Zealand in WW II, *IEEE Antennas Propagat. Magazine*, vol. 34, no 3, pp. 31-39, 1992.

6 P.K. Oshchepkov, *Notes of Engineer, Inventor and Scientist*, Moscow: Moskovsky Rabochy, 1965 (in Russian).

7. Y.B. Kobzarev, The first soviet pulse radar, *Radiotekhnika*, vol. 29, no 5, pp. 2-6, 1974 (in Russian).

8. M.M. Lobanov, *Beginning of Soviet Radar*, Moscow: Sov. Radio, 1975 (in Russian).

9. A.Y. Usikov, Draft memo on "Zenit" and "Rubin" radars, circa 1944, IRE Archive, Kharkov (in Russian).

10. Interview of A. Usikov, January 1994, recorded by V. Lapty.

11. Interview of S. Braude, November 1998, recorded by A. Kostenko.

12. A.A. Slutskin, D.S. Shteinberg, Obtaining the oscillations in cathode tubes with the aid of magnetic field, *J. of Russian Physico-Chemical Soc.*, vol. 58, no 2, pp. 395-407, 1926 (in Russian).

13. Y.V. Pavlenko, Y.N. Ranyuk, Y.A. Khramov, *The Case of UIPT*, Kiev: Feniks, 1998 (in Russian).

14. A.A. Slutzkin, P.P. Leljakow, E.A. Kopilowitsch, I.A. Wyschinsky, A.J. Usikow, Faktoren welchedie leistung und den wirkungsgrad von magnetronschwingungen beeinflussen, *Physicalische Zeitschrift der Sowjetunion*, vol. 5, no 6, pp. 887-901, 1934.

15. S.S. Vinogradov, P.D. Smith, E.D. Vinogradova, A.I. Nosich, Accurate simulation of a spherical reflector front-fed by a Huygens complex-source-point beam, *Proc. JINA-98*, Nice, pp. 550-553, 1998.

16. Y.I. Krivonosov, Landau and Sakharov in the KGB files, *Problems of History of Science and Technology*, no 3, pp. 123-132, 1993 (in Russian).